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(54) **Stator for electric machine and lamination thereof**

Stator für elektrische Maschine und Blechpaket hierfür

Stator pour machine électrique et son paquet de tôles

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Description

This invention relates to a stator for a rotating electrical machine. The invention is particularly, though not exclusively, applicable to a switched reluctance (SR) machine.

Rotating electrical machines can be arranged to run as generators or motors. Such machines of various types typically have stator laminations made of electrical sheet steel, having an outer lamination profile (which also constitutes the outer profile perpendicular to the axis of the stator) which is essentially circular, save for small keyways or cut-outs included to facilitate manufacture and/or assembly. The radially inner profile defines the stator teeth which interact with the rotor rotating inside the stator. These circular laminations are packed together, to form the axially extending stator, and mounted in a frame.

Laminations are also known which have a generally rectangular outer profile. These are often used in a so-called 'frameless' construction in which the relatively thicker corners of the stator back iron are used to bear a bolt or other clamping arrangement to hold the laminations together.

In some types of electrical machines, such as switched reluctance machines, a relatively small number of teeth are used and are normally called stator poles. Typically each stator pole is influenced by a coil which is one of a number connected in a group or groups to form machine phases. The selection of the number of poles and the number of coils in a group forming a phase are two of the parameters of machine design. For example, an SR machine with four stator poles could be connected to form two phases each of two coils, as shown in Figure 1, or an SR machine with twelve stator poles could be connected to form three phases each of four coils, as shown in Figure 2.

A body can be excited into mechanical resonance by applying an impulsive or periodic force. The amplitude of the resonance vibrations is dependent on the frequency and amplitude of the exciting force and the position at which it is applied, as well as on the material and proportions of the structure.

EP-A-0180815 discloses a lamination for a reluctance motor. The lamination has six stator poles. The outer profile of the lamination is generally square and the stator poles are arranged so that an opposed pair of interpole spaces extend into respective corners. The greater material in each corner is exploited to provide a deeper space to accommodate an additional field winding. A pair of opposed stator poles lie across the other diagonal. The purpose and effect of the energised field winding is not elaborated upon, but it is said to be usable with the skewed rotor, also disclosed, which is intended to modify the torque profile of the reluctance motor.

A body which has a geometrically regular shape will have a well-defined pattern of resonance, usually with a range of frequencies of vibration present at reso-

nance. The points on the body where vibration at a particular frequency gives rise to zero amplitude of vibration are known as nodes. The points at which the amplitude is at maximum are known as anti-nodes.

While it is known in the art of acoustic noise reduction to make the shape of a body irregular to minimise the effects of resonance, there is little or no opportunity to do this with laminations of common forms of electrical machines.

When a phase winding of an SR motor is excited, there is (in addition to the desired torque-producing force) a force generated which acts to pull the energised stator poles towards the centre of the machine. This has the effect of distorting the notional circle on which the end faces of the stator poles lie. Thus, successive energisation of the phases (in whatever sequence is desired for a particular mode of operation) imparts a periodic radial force to the structure of the laminations. This has the effect of cyclically distorting the laminations, the vibrations thus caused being responsible for producing acoustic noise.

It is an object of the present invention to provide a stator profile and a shape of lamination for a stator in which the tendency to vibration, giving rise to acoustic noise, is reduced.

According to the present invention there is provided a stator for a rotatable electrical machine, the stator comprising a body defining an outer ring and a plurality of stator poles which project radially inwardly from the ring and partially define a rotor space about an axis, the ring having a non-circular outer profile perpendicular to the said axis, which profile has at least one line of symmetry passing through the said axis, each pole being angularly intermediate radially thickest and thinnest parts of the ring and having a centre line which is angularly offset ($\theta/4$) from the or each line of symmetry of the said profile such that the body has no line of symmetry, thereby avoiding any pole centre line being angularly coincident with a vibrational antinode of the stator ring.

Further in accordance with the present invention, there is provided a lamination for a stator for a rotatable electrical machine, the lamination comprising a ferromagnetic body defining an outer ring and a plurality of stator pole profiles which project radially inwardly from the ring and partially define a rotor space about an axis, the ring having a non-circular outer profile perpendicular to the said axis, which profile has at least one line of symmetry passing through the said axis, each pole profile being angularly intermediate radially thickest and thinnest parts of the ring and having a centre line which is angularly offset ($\theta/4$) from the or each line of symmetry of the said pole profile such that the body has no line of symmetry, thereby avoiding any pole profile centre line being angularly coincident with a vibrational antinode of the stator ring.

A node of vibration may exist toward the relatively thickest part of the ring, whereas the antinode at which vibration of the greatest amplitude and frequency range

occurs will be nearer the relatively thinnest part of the ring. By positioning the pole to be centred away from the antinode, the forces tending to create the acoustic noise are of reduced effect.

The offset is desirably about one quarter of the angular stator pole pitch. Preferably, the line of symmetry from which the stator pole is offset is coincident with the radially thinnest part of the ring with respect to the said axis.

While the invention is particularly applicable to simple shapes, such as square profiles and four or eight poles, it is also relevant to any other number of stator poles and phases. For example, the outer profile may be square or hexagonal. The hexagonal outer profile may be used in a three-phase, six pole machine, whereas the square profile may be used in a two-phase, four pole machine. In general, a regular, even sided, shape of $4n$ sides (n an integer) is conveniently usable for a machine of n phases or $2n$ poles. However, the more sides to the polygonal outer profile there are, the more the shape approximates to a circle. The invention is not necessarily limited to regular arrangements of sides.

The stator may be for a switched reluctance machine having windings associated with the poles which are arranged to energise the poles. The stator windings may be arranged so that the stator poles of opposite polarity are disposed on opposite sides of the radially thinnest part of the ring. This is advantageous in a four or an eight stator pole machine. More particularly this advantage is realised in a 2 phase machine.

Preferably, the stator is made up of a plurality of laminations.

The invention extends to a lamination providing the outer profile and defining the stator poles as defined above.

Furthermore, the invention extends to an electrical machine having a stator as defined above, for example, a switched reluctance machine.

One purpose in offsetting the at least one stator pole is to make irregular the respective symmetries of the ring and the stator poles to reduce the amplitude of vibration at resonance.

The present invention can be put into practice in various ways some of which will now be described by way of example with reference to the accompanying drawings in which :

Figure 1 is a cross-section of a prior art stator for a two-phase switched reluctance machine;

Figure 2 is a cross-section of a prior art stator for a three-phase switched reluctance machine with only one phase winding shown;

Figure 3 is a cross-section of a switched reluctance machine according to the invention; and

Figure 4 is a cross-section of an alternative embod-

iment of a stator according to the invention.

Referring to Figure 3 of the drawings, a switched reluctance machine, which can be arranged to run either as a generator or a motor, comprises a stator 10 and a rotor 12. The stator 10 is made up of a plurality of laminations of electrical sheet steel. The cross-sectional profile of the stator, in a plane perpendicular to the axis of rotation of the rotor 12, comprises four equi-angularly spaced stator poles 14 which project radially inwardly from a radially outer ring of back iron 16. The outer profile of the stator is square, having a centre coincident with the axis 17 of the notional circle on which the radially inner end faces 18 at the poles 14 are arranged. The roots of the stator poles 14 are joined by sections of the ring of back iron 16 defining a circle 20 having a centre also coincident with the axis of rotation of the rotor.

The rotor defines two equiangularly spaced rotor poles 22 which rotate about the axis 17 of the stator pole faces 18. Having a rectangular outer shape, the ring of back iron 16 has relatively thicker and thinner portions relative to the circle 20 from which the poles 14 project. When the poles are arranged symmetrically with respect to the outer profile of the stator (as shown in Figure 1), the position of the ovalising force pulling on the stator pole coincides with the position at which the antinode would occur if the structure vibrated in response to the ovalising force. In the prior art arrangement, the structure relatively easily achieves substantial resonance in which the amplitude of the vibrations makes the condition noticeable in the presence of relatively small ovalising forces.

In Figure 3 the angular axis of each stator pole 14 is shifted from a symmetrical position by one quarter of the angle of the pole pitch θ . Thus, the position of the exciting force is asymmetrical to the stator profile, i.e. the angular position of the stator pole is shifted to one intermediate the thickest and thinnest radial extent of the stator back iron and the antinodes of all the low order harmonics are avoided. Thus, for a magnitude of exciting force which is substantially unchanged, the amplitude of the vibration at resonance is reduced which limits the amount of acoustic noise created.

When the outer profile of the stator is substantially square it is possible to use the invention with any number of phases, each phase number having an optimum angular position for the stator pole between adjacent thickest and thinnest portions on the back iron.

Figure 4 shows an eight pole machine stator 24 having a square outer profile. Stator poles 26 are angularly offset $\theta/4$ from the thinnest portion of the back iron which corresponds to a line of symmetry passing through the centre 17.

Similarly, where the number of phases is greater than two and the outer profile has more than four sides, the invention may be used, positioning each stator pole at a position $\theta/4$ from the thinnest part of the back iron. For example, a three-phase machine having an hexag-

onally profiled stator will have the position of each stator pole arranged to be between the relatively thinner and thicker portions of the back iron, e.g. shifted $\theta/4$.

There is a further benefit of the invention which accrues when certain pole and phase number combinations are used with certain outer profiles, for example, a two-phase machine with four or eight poles and a substantially square outer profile. In Figures 3 and 4, sections of the back iron of the stator are effectively narrower than other parts. When one phase of the machine is excited this gives rise to a higher flux density in those sections than in other sections. This would normally be considered to be a limiting aspect of the design. There is the opportunity, however, to reduce this disadvantage by connecting the phase windings to the supply with a particular polarity.

The coil (not shown) around pole 14A of Figure 3 is connected to the supply so as to produce a 'north' pole and the coil around the pole 14B produces a 'south' pole. There is then a choice as to the connection of poles 14C and 14D. Either pole 14C is connected to produce a 'north' pole and pole 14D will then be a 'south' pole, so that like polarities are on opposite sides of the narrow part of the back of iron. Alternatively, pole 14C is connected to produce a 'south' pole and pole 14D will then be a 'north' pole, so that opposite polarities are on opposite sides of the narrow section. If the machine is connected in the latter fashion and operated with an excitation pattern which involves flux existing simultaneously in both phases, then flux waveforms are produced which have lower flux densities in the narrow section. This leads to lower excitation requirements and lower iron losses than would have been the case if the machine had been connected in the former fashion.

Various embodiments of the invention have been described by way of example. Variations are possible within the scope of the appended claims.

Claims

1. A stator (10) for a rotatable electrical machine, the stator comprising a body defining an outer ring (16) and a plurality of stator poles (14) which project radially inwardly from the ring and partially define a rotor space about an axis, the ring having a non-circular outer profile perpendicular to the said axis, which profile has at least one line of symmetry passing through the said axis, each pole being angularly intermediate radially thickest and thinnest parts of the ring and having a centre line which is angularly offset ($\theta/4$) from the or each line of symmetry of the said profile such that the body has no line of symmetry, thereby avoiding any pole centre line being angularly coincident with a vibrational antinode of the stator ring.
2. A stator as claimed in claim 1 in which the stator poles define an angular pole pitch (θ), the said offset of the centre line of each stator pole adjacent a line of symmetry being one quarter of the pole pitch ($\theta/4$).
3. A stator as claimed in claim 1 or 2 in which the line of symmetry from which the centre line of each pole is offset is coincident with the radially thinnest part of the ring with respect to the said axis.
4. A stator as claimed in claim 1 in which the outer profile is square.
5. A stator as claimed in claim 4 including four poles.
6. A stator as claimed in claim 1, 2 or 3 in which the outer profile is hexagonal.
7. A stator as claimed in claim 6 including six poles.
8. A stator as claimed in claim 1 or 2 in which the outer profile has the same number of sides as poles.
9. An electrical machine comprising a rotor and a stator as claimed in any preceding claim.
10. A machine as claimed in claim 9, including phase windings defining n phases, the outer profile having $2n$ sides and the stator having $2n$ poles (n an integer).
11. A machine as claimed in claim 9 or 10, including stator windings, the machine being constructed and arranged to run as a reluctance machine.
12. A machine as claimed in claim 11 in which the stator poles of opposite plurality are disposed on opposite sides of the thinnest part of the ring.
13. A lamination for a stator (10) for a rotatable electrical machine, the lamination comprising a ferromagnetic body defining an outer ring (16) and a plurality of stator pole profiles (14) which project radially inwardly from the ring and partially define a rotor space about an axis, the ring having a non-circular outer profile perpendicular to the said axis, which profile has at least one line of symmetry passing through the said axis, each pole profile being angularly intermediate radially thickest and thinnest parts of the ring and having a centre line which is angularly offset ($\theta/4$) from the or each line of symmetry of the said pole profile such that the body has no line of symmetry, thereby avoiding any pole profile centre line being angularly coincident with a vibrational antinode of the stator ring.
14. A lamination as claimed in claim 13 in which the stator pole profiles define an angular pole pitch (θ), the

said offset of the centre line of each stator pole profile, adjacent a line of symmetry being about one quarter of the pole pitch ($\theta/4$).

15. A lamination as claimed in claim 14 in which the line of symmetry from which the centre line of each pole profile is offset is coincident with the radially thinnest part of the ring with respect to the said axis.
16. A lamination as claimed in claim 13, 14 or 15 which defines n pole profiles and in which the outer profile has n sides (n an integer).

Patentansprüche

1. Stator für eine rotierende elektrische Maschine, **dadurch gekennzeichnet, daß** der Stator einen Körper aufweist, der einen Außenring (16) und eine Anzahl von Statorpolen (14) bildet, welche von dem Ring radial nach innen stehen, und zum Teil einen Rotorraum um eine Achse bilden, wobei der Ring ein nicht kreisförmiges Außenprofil senkrecht zur Achse aufweist, welches zumindest eine Symmetrielinie besitzt, die durch die Achse verläuft, und jeder Pol sich im Winkelabstand zwischen den radial dicksten und dünnsten Abschnitten des Ringes befindet und eine Mittellinie aufweist, die winklig um ($\theta/4$) von der oder jeder Symmetrielinie des Profils so versetzt ist, daß der Körper keine Symmetrielinie aufweist, und dadurch verhindert wird, daß irgendeine Pol-Mittellinie winklig mit einem Schwingungsgegenknoten des Statorringes zusammenfällt.
2. Stator nach Anspruch 1, **dadurch gekennzeichnet, daß** die Statorpole eine winklige Poleinteilung (θ) bilden, wobei der Versatz der Mittellinie jedes Statorpoles neben einer Symmetrielinie ein Viertel der winkligen Poleinteilung ($\theta/4$) beträgt.
3. Stator nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** die Symmetrielinie, von welcher die Mittellinie jedes Poles versetzt ist, mit dem radial dünnsten Abschnitt des Ringes in bezug zur Achse zusammenfällt.
4. Stator nach Anspruch 1, **dadurch gekennzeichnet, daß** das Außenprofil quadratisch ist.
5. Stator nach Anspruch 4, **dadurch gekennzeichnet, daß** er vier Pole umfaßt.
6. Stator nach Anspruch 1, 2 oder 3, **dadurch gekennzeichnet, daß** das Außenprofil sechseckig ist.
7. Stator nach Anspruch 6, **dadurch gekennzeichnet, daß** er sechs Pole umfaßt.

8. Stator nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** das Außenprofil dieselbe Anzahl von Seiten wie Pole besitzt.

9. Elektrische Maschine, **dadurch gekennzeichnet, daß** sie einen Rotor und einen Stator nach einem oder mehreren der vorhergehenden Ansprüche aufweist.

10. Elektrische Maschine nach Anspruch 9, **dadurch gekennzeichnet, daß** sie Phasenwicklungen umfaßt, welche n Phasen bilden, und daß das Außenprofil 2n Seiten sowie der Stator 2n Pole aufweisen (n ganzzahlig).

11. Elektrische Maschine nach Anspruch 9 oder 10, **dadurch gekennzeichnet, daß** sie Statorwicklungen aufweist und so konstruiert und angeordnet ist, daß sie als Reluktanzmaschine betrieben wird.

12. Elektrische Maschine nach Anspruch 11, **dadurch gekennzeichnet, daß** die Statorpole in entsprechender Anzahl an den dünnsten Abschnitten des Ringes gegenüberliegenden Seiten angeordnet sind.

13. Blechpaket für einen Stator (10) einer rotierenden elektrischen Maschine, **dadurch gekennzeichnet, daß** das Blechpaket einen ferromagnetischen Körper umfaßt, welcher einen Außenring (16) bildet, sowie eine Anzahl von Statorpolprofilen (14), welche von dem Ring radial nach innen stehen und zum Teil einen Rotorraum um eine Achse bilden, wobei der Ring ein nicht kreisförmiges Außenprofil senkrecht zur Achse aufweist, welches zumindest eine Symmetrielinie aufweist, die durch die Achse verläuft, und jeder Pol, der sich im Winkelabstand zwischen den radial dicksten und dünnsten Abschnitten des Ringes befindet, eine Mittellinie aufweist, die winklig um ($\theta/4$) von der oder jeder Symmetrielinie des Polprofils so versetzt ist, daß der Körper keine Symmetrielinie aufweist, und dadurch verhindert wird, daß irgendeine Polprofil-Mittellinie winklig mit einem Schwingungsgegenknoten des Statorringes zusammenfällt.

14. Blechpaket nach Anspruch 13, **dadurch gekennzeichnet, daß** die Statorpolprofile eine winklige Poleinteilung (θ) bilden, und der Versatz der Mittellinie jedes Statorpolprofils neben einer Symmetrielinie etwa ein Viertel der Poleinteilung ($\theta/4$) beträgt.

15. Blechpaket nach Anspruch 14, **dadurch gekennzeichnet, daß** die Symmetrielinie, von welcher die Mittellinie jedes Poles versetzt ist, mit dem in bezug zur Achse radial dünnsten Abschnitt des Ringes zusammenfällt.

16. Blechpaket nach Anspruch 13, 14 oder 15, **dadurch gekennzeichnet, daß** dieses n Polprofile bildet, und das Außenprofil n Seiten aufweist (n ganzzahlig).

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Revendications

1. Stator (10) pour une machine électrique tournante, le stator comprenant un corps définissant un anneau externe (16) et une pluralité de pôles statoriques (14) qui font saillie radialement vers l'intérieur de l'anneau et définissent partiellement un espace de rotor autour d'un axe, l'anneau ayant un profil externe non circulaire perpendiculaire audit axe, lequel profil a au moins une ligne de symétrie passant par ledit axe, chaque pôle étant disposé en position angulaire intermédiaire entre des parties très épaisses et très minces radialement de l'anneau et ayant une ligne centrale qui est décalée angulairement ($\theta/4$) de la ou de chaque ligne de symétrie dudit profil de telle sorte que le corps n'ait pas de ligne de symétrie, évitant ainsi à une ligne centrale de pôle quelconque de coïncider en position angulaire avec un ventre de vibration de l'anneau du stator.
2. Stator selon la revendication 1, dans lequel les pôles statoriques définissent un pas de pôle angulaire (θ), ledit décalage de la ligne centrale de chaque pôle statorique adjacent à une ligne de symétrie étant d'un quart du pas polaire ($\theta/4$).
3. Stator selon la revendication 1 ou 2, dans lequel la ligne de symétrie dont la ligne centrale de chaque pôle est décalée, coïncide avec la partie radialement la plus mince de l'anneau par rapport audit axe.
4. Stator selon la revendication 1, dans lequel le profil externe est carré.
5. Stator selon la revendication 4, comprenant quatre pôles.
6. Stator selon la revendication 1, 2 ou 3, dans lequel le profil externe est hexagonal.
7. Stator selon la revendication 6, comprenant six pôles.
8. Stator selon la revendication 1 ou 2, dans lequel le profil externe a le même nombre de cotés que de pôles.
9. Machine électrique comprenant un rotor et un stator selon l'une quelconque des revendications précédentes.

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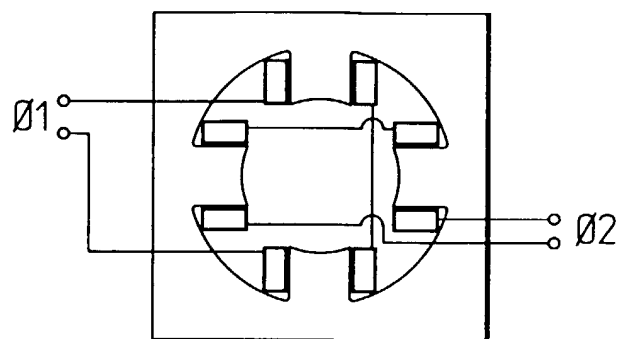
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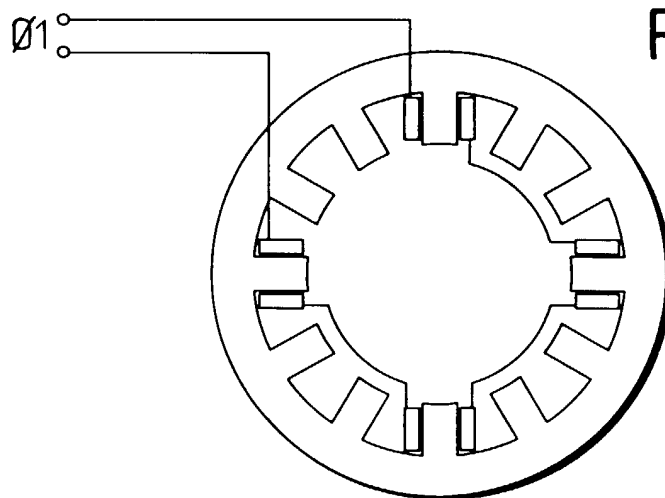
10. Machine selon la revendication 9, comprenant des enroulements de phase définissant n phases, le profil externe ayant 2 n cotés et le stator ayant 2 n pôles (n est un nombre entier).
11. Machine selon la revendication 9 ou 10, comprenant des enroulements de stator, la machine étant construite et agencée de manière à tourner en machine à réluctance.
12. Machine selon la revendication 11, dans laquelle les pôles statoriques de polarité opposée sont disposés sur des cotés opposés de la partie la plus mince de l'anneau.
13. Paquet de tôles pour un stator (10) de machine électrique tournante, le paquet de tôles comprenant un corps ferromagnétique définissant un anneau externe (16) et une pluralité de profils (14) de pôles statoriques qui font saillie radialement vers l'intérieur de l'anneau et définissent partiellement un espace de rotor autour d'un axe, l'anneau ayant un profil externe non circulaire perpendiculaire audit axe, ledit profil ayant au moins une ligne de symétrie passant par ledit axe, chaque profil de pôle étant disposé en position angulaire intermédiaire entre des parties très épaisses et très minces radialement de l'anneau et ayant une ligne centrale qui est décalée angulairement ($\theta/4$) de la ou de chaque ligne de symétrie dudit profil de pôle de telle sorte que le corps n'ait pas de ligne de symétrie, évitant ainsi que n'importe quelle ligne centrale de profil de pôle coïncide en position angulaire avec un ventre de vibration de l'anneau du stator.
14. Paquet de tôles selon la revendication 13, dans lequel les profils des pôles statoriques définissent un pas polaire angulaire (θ), ledit décalage de la ligne centrale de chaque profil de pôle statorique adjacente à une ligne de symétrie étant d'environ un quart du pas polaire ($\theta/4$).
15. Paquet de tôles selon la revendication 14, dans lequel la ligne de symétrie dont la ligne centrale de chaque profil de pôle est décalée, coïncide avec la partie radialement la plus mince de l'anneau par rapport audit axe.
16. Paquet de tôles selon la revendication 13, 14 ou 15, qui définit n profils de pôles et dans lequel le profil externe a n cotés (n est nombre entier).

FIG.1.



PRIOR ART

FIG.2.



PRIOR ART

FIG. 3.

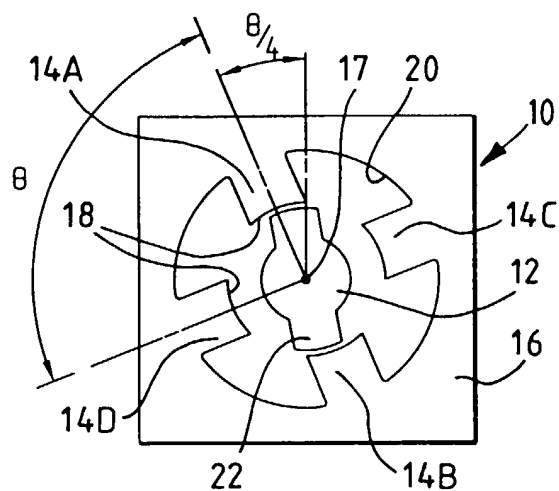


FIG. 4.

